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STATE SELECTION IN ELECTRON-ATOM SCATTERING: SPIN-POLARIZED ELECTRON SCATTERING FROM OPTICALLY PUMPED SODIUM

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When an electron collides with an atom, there are generally many quantum channels through which the scattering can take place. These can involve several energetically accessible channels, several angular momentum states degenerate in energy, and several spin states also degenerate in energy. A theoretical calculation of the scattering must examine each of the channels individually, and then perform an average over those not separated in the experiment with which comparison is to be made.

If one wishes to perform an experiment that provides the most rigorous test of theory, it is clear that averaging over different channels is to be avoided, since specific discrepancies cannot easily be separated from each other. Thus an energy-resolved scattering experiment provides more information than an energy-averaged one, an energy- and target angular momentum-resolved experiment provides even more detailed information, and an energy-, target angular momentum- and spin-resolved experiment provides the most information possible.

In low-energy electron scattering from a light, "one-electron" atom such as sodium, nearly complete state-selection can be accomplished by spin-polarizing the incident electron and measuring superelastic scattering from an optically pumped atom in the first $3^2P_{3/2}$ excited state. Superelastic scattering involves measuring only those electrons which have de-excited the $3^2P_{3/2}$ atom and gained the 2.1 eV excitation energy, so energy selection is achieved. Optically pumping the atom with definite light polarization means that individual angular momentum states can be selected. Spin-polarizing the incident electron allows for spin state selection because the incident electron will form either a singlet or triplet state with the target electron, depending on the relative orientations of the two electrons' spins.

We have performed measurements of spin-polarized superelastic scattering from $Na(3^2P_{3/2})$ optically pumped with both linearly[1] and circularly[2] polarized light over the incident energy range 1.3 - 9.3 eV and angular range 0° to 40°. The results are presented in terms of spin asymmetries, defined as

$$A = \frac{1}{P_e} \frac{I(\downarrow) - I(\uparrow)}{I(\downarrow) + I(\uparrow)} . \qquad (1)$$

where P_e is the incident electron polarization and I is the scattering intensity for incident spin "up" ($\uparrow$) or "down" ($\downarrow$) electrons.

The apparatus, shown in Figure (1), consists of a GaAs polarized electron source, a conventional effusive recirculating sodium beam source, a single-frequency, stabilized ring dye laser for optical pumping, and a channel electron multiplier with a retarding field analyzer mounted on a rotating turntable.

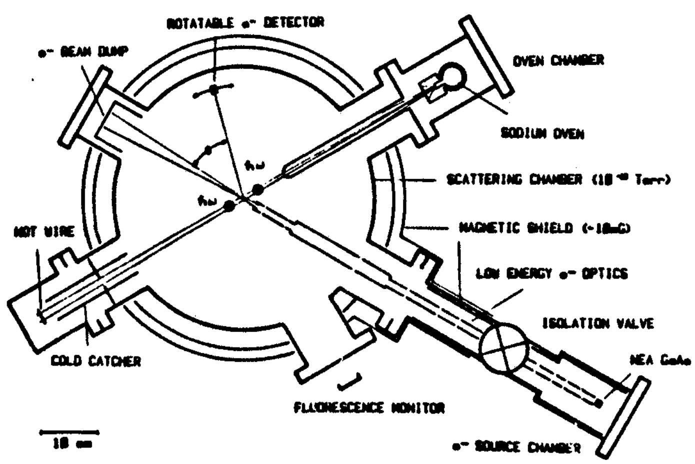

Figure 1. Experimental Apparatus.

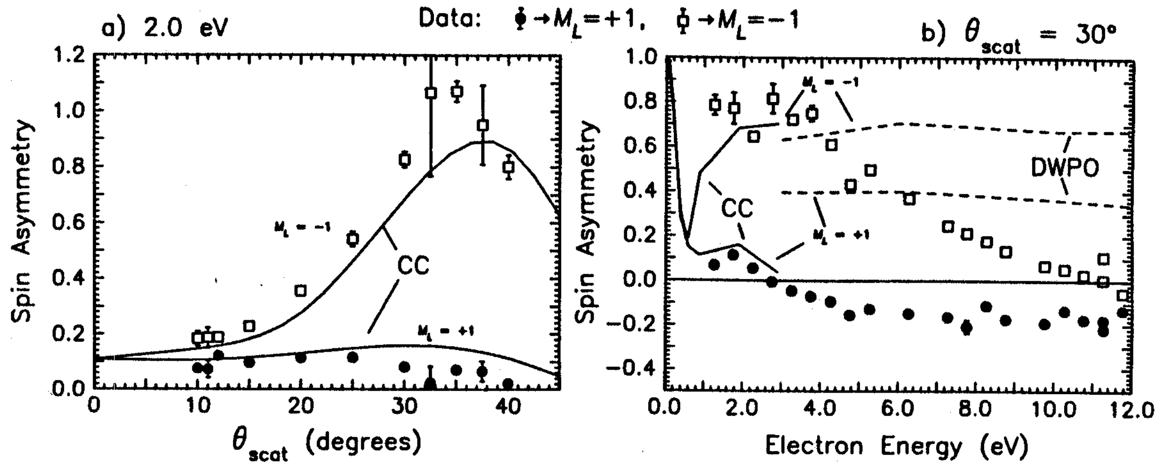

Figure 2. Spin asymmetries for superelastic electron scattering from sodium pumped with circular polarization - (a) vs. scattering angle, and (b) vs. incident energy. Theory is close coupling (CC) from Ref. (3) and distorted wave-polarized orbital (DWPO) from Ref. (4).

Examples of measured spin asymmetries are shown in Figures (2a) and (2b), where the results from circularly polarized excitation are shown. Two curves are displayed in each figure, one for optical pumping with left-handed circular polarization (LHC) and one for right-handed (RHC). LHC (or RHC) light incident perpendicularly from above the scattering plane produces atoms in a pure $M_L = -1$ (or $M_L = +1$) orbital angular momentum state, as descibed in the "natural" frame, which has its z-axis perpendicular to the scattering plane. It also spin-polarizes the target electron in the same direction as M_L. Thus we can measure spin asymmetries individually for these two pure orbital angular momentum states. As can be seen, they have widely differing behavior.

The solid lines in each figure represent theory; the lower energy values are derived from a close-coupling calculation[3] and the higher energy values come from a distorted-wave polarized-orbital (DWPO) calculation.[4] Good agreement is observed with the close-coupling calculation, but serious disagreement is evident with the DWPO results.

In addition to using spin asymmetries as described above, one can describe the results presented here in the framework of orientation and alignment of the atom produced in the time-inverse, inelastic collision.[5] With spin analysis added to the formalism one can in principle extract six numbers – $L_{\perp}^{s}$, $L_{\perp}^{t}$, P_{lin}^{s}, P_{lin}^{t}, γ^{s} and γ^{t}, where $L_{\perp}$ is the angular momentum transferred to the atom, P_{lin} is the degree of polarization of the charge cloud after excitation, and γ is the "tip" angle of the charge cloud. The superscripts "s" and "t" refer to whether the excitation happened via a singlet or triplet channel. Discussion of this in some detail will be included in the presentation.

These measurements show that, in at least one system, theory can be examined with unprecedented detail. The experiments described here are not "complete", however, because the relative phase between the triplet and singlet scattering channels is not probed. This can be accomplished only by measuring the polarization of the scattered electrons in addition to polarizing the incident electrons. Work is currently under way to incorporate spin analysis in the detection system so that a truly "complete" experiment can be performed.

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5. See, e.g., N. Andersen, in invited papers of the XIV ICPEAC, Palo Alto, CA (1985).